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Q1. Rocks that contain carbonates, such as limestone, are the most effective at neutralizing the effects of acid deposition.

Q2. The only way to completely eliminate the effects of acid rain is to stop putting SO_x and NO_x into the atmosphere. We would have to stop burning oil and gas in factories, power plants and home furnaces. Automobiles and trucks would be at a standstill, and metal refineries would close. We cannot go back to a time when these activities were unknown. The aid should instead point out responsible ways to reduce the emissions that cause acid deposition: using low sulfur content fuels, saving energy at home and in factories, promoting public transport and increased fuel efficiency for cars and trucks. There might be tax incentives to stimulate change, especially for industries that reduce their emissions of harmful gases. The technology already exists to reduce the emissions that cause acid deposition. The real question is, are we willing to pay for this technology? Also, since the problem is global, are we willing to help developing countries with this technology?

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1. Major sources of emissions that cause acid deposition are fossil-fuel combustion (releasing mainly $SO_2(g)$, but also $SO_3(g)$), from coal-fired power plants, but also from the combustion of oil or gas in furnaces. Refining metal ores also releases large quantities of $SO_2(g)$ and $SO_3(g)$. In Alberta, the major sources of sulfur dioxide emissions are the oil sands projects and power plants. Gas plant flares, oil refineries, pulp and paper mills and fertilizer plants also contribute to the problem. Transportation and power plants are the major sources of $NO(g)$ and $NO_2(g)$.

Natural sources of SO_x include releases from the oceans, biological decay, forest fires, and volcanoes. The Kilauea volcano in Hawaii is one of the most active in the world, and acid rain from the volcano has resulted in a large desert area near the crater.

2. Students should identify parts of Canada with large capacities for electric power generators using fossil fuels, and areas with mining and smelting activities. These are principally located in Ontario and Quebec. Emissions that impact western Canada are located in Alberta, southern Saskatchewan and northern Manitoba.
3. A lake or stream may have a lower pH in the spring than at any other time of the year if there is a relatively sudden melting of acidic snow that feeds into the waterway.
4. Carbonic acid is a **much** weaker acid than the other acids of concern.
5. Acid rain affects stone buildings and bridges, marble building facades, concrete and mortar, because these materials contain carbonates that react with acid rain.
6. These strategies should focus on ways to consume less energy from fossil fuel sources. Strategies could include walking, cycling, or using public transport rather than an automobile; turning the thermostat down at night and consuming less energy; insulating doors, windows and attics.

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Q3. The Arrhenius theory is restricted because it applies only to acid-base reactions in aqueous solution. Also, the Arrhenius theory recognizes only one kind of base, the hydroxide ion. The Brønsted-Lowry theory is more general because it removes each of these restrictions.

Q4. Look for answers that clearly show a substance capable of accepting a proton, but which do not form the hydroxide ion in solution. Aqueous ammonia, $NH_3(aq)$, is one frequent answer, but any amine might be chosen. Other good answers include anions such as $HCO_3^-(aq)$ and $HSO_4^-(aq)$.

Q5. A Brønsted-Lowry acid must contain H^+, because it is defined as a proton donor. However, a Brønsted-Lowry base does not have to contain OH^-, because it is defined as a proton acceptor.

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For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

1. (a) fluoride ion, $F^-(aq)$

(b) carbonate ion, $CO_3^{2-}(aq)$

(c) hydrogen sulfate ion, $HSO_4^-(aq)$

(d) hydrazine, $N_2H_4(aq)$

2. (a) nitric acid, $HNO_3(aq)$

(b) water, $H_2O(\ell)$

(c) hydronium ion, $H_3O^+(aq)$

(d) carbonic acid, $H_2CO_3(aq)$

3. $HClO_4(aq)/ClO_4^-(aq)$ and $H_2O(\ell)/H_3O^+(aq)$.

4. (a) $H_2O(\ell)/OH^-(aq)$ and $HS^-(aq)/H_2S(aq)$.

(b) $H_2O(\ell)/OH^-(aq)$ and $O^{2-}(aq)/OH^-(aq)$.

(c) $H_2S(aq)/HS^-(aq)$ and $NH_3(aq)/NH_4^+(aq)$

(d) $H_2SO_4(aq)/HSO_4^-(aq)$ and $H_2O(\ell)/H_3O^+(aq)$

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For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

5. (a) $H_2S(aq) + H_2O(\ell) \rightleftharpoons HS^-(aq) + H_3O^+(aq)$

$HS^-(aq) + H_2O(\ell) \rightleftharpoons S^{2-}(aq) + H_3O^+(aq)$

(b) $HS^-(aq) + H_2O(\ell) \rightleftharpoons H_2S(aq) + OH^-(aq)$

6. (a) $HCO_3^-(aq) + OH^-(aq) \rightleftharpoons CO_3^{2-}(aq) + H_2O(\ell)$

(b) $HCO_3^-(aq) + HF(aq) \rightleftharpoons H_2CO_3(aq) + F^-(aq)$

7. Acid: $H_2PO_4^-(aq) + H_2O(\ell) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$

Base: $H_2PO_4^-(aq) + H_2O(\ell) \rightleftharpoons H_3PO_4(aq) + OH^-(aq)$

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8. (a) left, reactants are favoured

(b) left, and reactants are favoured

(c) left, reactants are favoured

9. (a) left, reactants are favoured

(b) right, products are favoured

(c) right, products are favoured

10. (a) product favoured

$H_2CO_3(aq) + NH_3(aq) \rightleftharpoons NH_4^+(aq) + HCO_3^-(aq)$

(b) reactant favoured

$Na^+(aq) + HSO_3^-(aq) + H_2O(\ell) \rightleftharpoons Na^+(aq) + SO_3^{2-}(aq) + H_3O^+(aq)$

(c) reactants favoured

$K^+(aq) + NO_3^-(aq) + HF(aq) \rightleftharpoons K^+(aq) + HNO_3(aq) + F^-(aq)$

(d) reactants favoured

$H_3PO_4(aq) + H_2O(\ell) \rightleftharpoons H_2PO_4^-(aq) + H_3O^+(aq)$

$H_2PO_4^-(aq) + H_2O(\ell) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$

$HPO4^{2-}(aq) + H_2O(\ell) \rightleftharpoons PO_4^{3-}(aq) + H_3O^+(aq)$

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1. The conjugate acid-base pairs are $CH_3COOH(aq)/CH_3COO^-(aq)$ and $H_2O(\ell)/OH^-(aq)$
2. The acids in this reaction are $H_2PO_4^-(aq)$ and $NH_4^+(aq)$. Looking at Table 17.1 on page 689, the stronger acid is $H_2PO_4^-(aq)$. Therefore, the reaction proceeds to the right as written, and products are favoured.
3. $H_3BO_3(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + H_2BO_3^-(aq)$
   $H_2BO_3^-(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HBO_3^{2-}(aq)$
   $HBO_3^{2-}(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + BO_3^{3-}(aq)$
4. The conjugate acid-base pairs are:
   (a) $H_2PO_4^-(aq)/HPO_4^{2-}(aq)$ and $HCO_3^-(aq)/CO_3^{2-}(aq)$
   (b) $HCOOH(aq)/HCOO^-(aq)$ and $HCN(aq)/CN^-(aq)$
   (c) $H_2PO_4^-(aq)/HPO_4^{2-}(aq)$ and $H_2O(\ell)/OH^-(aq)$

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11.

(a) $$K_a = \frac{[H_3O^+][NO_2^-]}{[HNO_2]} = 5.6 \times 10^{-4}$$

(b) $$K_a = \frac{[H_3O^+][C_6H_5COO^-]}{[C_6H_5COOH]} = 6.3 \times 10^{-5}$$

(c) $$K_a = \frac{[H_3O^+][H_2C_6H_5O_7^-]}{[H_3C_6H_5O_7]} = 7.4 \times 10^{-4}$$

(d) $$K_a = \frac{[H_3O^+][C_6H_5O_7^{3-}]}{[HC_6H_5O_7^{2-}]} = 4.0 \times 10^{-7}$$

12. $K_{a2} = \dfrac{[HCO_3^-][H_3O^+]}{[H_2CO_3]}$ $K_{a1} = \dfrac{[CO_3^{2-}][H_3O^+]}{[HCO_3^-]}$

13. $C_6H_6O(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + C_6H_5O^-(aq)$

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14. $K_a = 1.0 \times 10^{-4}$

percent ionization = 3.2%

15. $K_a = 1.5 \times 10^{-5}$, 3.9%

16. $K_a = 6.1 \times 10^{-10}$

17. $K_a = 1.2 \times 10^{-5}$

18. 13%

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Q6. The ion product, K_w, is an equilibrium constant. The equilibrium constant is affected only by changes in temperature. The ions in water are in equilibrium. When an acid is added, the concentration of hydronium ion, $H_3O^+(aq)$, is increased. This will cause the equilibrium to shift, decreasing the concentration of the ions, and maintaining K_w.

Q7. The ionization of water at 25 °C results in $[H_3O^+(aq)] = [OH^-(aq)] = 1.0 \times 10^{-7}$ mol/L. These concentrations are not significant unless a very dilute solution of an acid or base is present. The concentrations of hydronium ion and hydroxide ion due to the ionization of water are not important in any problem in this text.

Q8. Diluting the acid will result in the position of equilibrium being shifted to the right. Thus, as the acid is diluted, it becomes a stronger acid.

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19. (a) $NH_3(aq) + H_2O(\ell) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

(b) $(CH_3)_3N(aq) + H_2O(\ell) \rightleftharpoons (CH_3)_3NH^+(aq) + OH^-(aq)$

(c) $HSO_3^-(aq) + H_2O(\ell) \rightleftharpoons H_2SO_3(aq) + OH^-(aq)$

(d) $CO_3^{2-}(aq) + H_2O(\ell) \rightleftharpoons HCO_3^-(aq) + OH^-(aq)$

20. (a) $K_b = \dfrac{[NH_4^+][OH^-]}{[NH_3]}$

(b) $K_b = \dfrac{[(CH_3)_3NH^+][OH^-]}{[(CH_3)_3N]}$

(c) $K_b = \dfrac{[H_2SO_3][OH^-]}{[HSO_3^-]}$

(d) $K_b = \dfrac{[HCO_3^-][OH^-]}{[CO_3^{2-}]}$

21. Percent ionization 0.044 %

22. $K_b = 1.7 \times 10^{-6}$

23. $K_b = 1.4 \times 10^{-9}$

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For full solutions to the practice problems, visit **www.albertachemistry.ca,** Online Learning Centre, Instructor Edition, Full Solutions.

24. 0.47%, pH = 2.41

25. 2.5%, pH = 1.60

26. $K_a = 2.9 \times 10^{-8}$

27. 1.01×10^{-2} g

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28. pH 11.14

29. pH 10.04

30. $K_b = 1.6 \times 10^{-6}$

31. $[OH^-(aq)] = 2.6 \times 10^{-2}$ mol/L; pOH = 1.58

32. $[OH^-(aq)] = 3.7 \times 10^{-3}$ mol/L, 1.7%

33. $[NH_3(aq)] = 2.8 \times 10^{-2}$ mol/L

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For full solutions to the practice problems, visit **www.albertachemistry.ca**, Online Learning Centre, Instructor Edition, Full Solutions.

34. (a) $CN^-(aq)$, $K_b = 1.6 \times 10^{-5}$

(b) $NO_2^-(aq)$, $K_b = 1.8 \times 10^{-11}$

35. The conjugate acid of CH_3NH_2 is $CH_3NH_3^+$ (aq) for which $K_a = 2.3 \times 10^{-11}$.

The conjugate acid of $C_5H_5N(aq)$ is $C_5H_5NH^+(aq)$ for which $K_a = 7.1 \times 10^{-6}$

36. $CN^-(aq)$ is the stronger base.

37. Use $K_{a2} \bullet K_b$ for $S^{2-}(aq) = 1.0 \times 10^5$

38. $NH_4^+(aq)$ is the weaker acid. The reaction proceeds to the right and products are favoured.

Student Textbook page 704

1. (a) as an acid: $HPO_4^{2-}(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + PO_4^{3-}(aq)$

as a base: $HPO_4^{2-}(aq) + H_2O(\ell) \rightleftharpoons OH^-(aq) + H_2PO_4^-(aq)$

(b) $K_a = \dfrac{[H_3O^+(aq)][PO_4^{3-}(aq)]}{[HPO_4^{2-}(aq)]}$

(c) $K_b = \dfrac{[OH^-(aq)][H_2PO_4^-(aq)]}{[HPO_4^{2-}(aq)]}$

(d) The solution is basic because K_b is greater than K_a.

2. (a) The stronger Brønsted-Lowry acid is $H_3O^+(aq)$. Polar water molecules will be more strongly attracted to positive hydronium ions than to neutral carbonic acid molecules.

(b) The stronger Brønsted-Lowry acid is $HSO_4^-(aq)$. The four oxygen atoms pull electrons away from the hydrogen atom that will ionize, making the bond polar. Sulfur is a fairly electronegative atom, and this increases the partial charge on the hydrogen atom in $HSO_4^-(aq)$.

(c) $H_2AsO_4^-(aq)$ is the stronger Brønsted-Lowry acid. It will require more energy to remove a proton from $HAsO_4^{2-}(aq)$ because it has a double negative charge.

3. (a) The stronger Brønsted-Lowry base is $SO_3^{2-}(aq)$. Polar water molecules will be more strongly attracted to negative sulfite ions.

(b) The stronger Brønsted-Lowry base is $F^-(aq)$. Although the ions have the same charge, the fluoride ion has a smaller radius. The charge density on $F^-(aq)$ is greater, and this ion is able to remove a proton from water more easily than $Cl^-(aq)$.

(c) The stronger Brønsted-Lowry base is $O_2^{2-}(aq)$. The oxide ion is smaller and has a larger negative charge than the hydroxide ion.

4. (a) The conjugate base is $C_6H_7O_6^-(aq)$.

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{9.1 \times 10^{-5}} = 1.1 \times 10^{-10}$$

(b) The conjugate base is $CH_3COO^-(aq)$.

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.6 \times 10^{-10}$$

(c) The conjugate base is $HCOO^-(aq)$.

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-4}} = 5.6 \times 10^{-11}$$

5. $CH_3NH_3^+(aq)$ is the stronger acid because $CH_3NH_2(aq)$ is the weaker base.

6. (a) Reactants are favoured because $H_3O^+(aq)$ is a stronger acid than $NH_4^+(aq)$.

(b) Reactants are favoured because $H_2SO_4(aq)$ is a stronger acid than $H_3O^+(aq)$.

(c) Reactants are favoured because $H_2S(aq)$ is a stronger acid than $HSO_3^-(aq)$.

(d) Products are favoured because $HF(aq)$ is a stronger acid than $HCO_3^-(aq)$.

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Q9. (a) The equivalence point in a titration is the point at which the number of moles of an unknown solution is equal to the number of moles of a standard solution. The endpoint in a titration is the point at which an indicator turns colour.

(b) When choosing an indicator, it does not need to coincide exactly. The endpoint range of the indicator should include the pH of the equivalence point.

Q10. At the equivalence point where neutralization is complete, the solution may contain ions that react with water (hydrolyze). The conjugate base of a weak acid will react with water to form a basic solution. The conjugate acid of a weak base will react with water to form an acid solution.

Q11. Checking the region of the pH scale over which the colour change for the indicators overlap, we can say that bromocresol green is blue and methyl red is orange from pH = 4.5 to pH 5.5.

Q12. Sodium hydroxide is a strong base and nitric acid is a strong acid. The pH at the equivalence point will be 7, since neither the cation nor the anion of the salt that forms from the neutralization will hydrolyze. Phenolphthalein or bromothymol blue would include pH = 7 in the range over which they change colour.

Student Textbook page 718

1. (a) $KOH(aq) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O(\ell)$

(b) $H_3PO_4(aq) + 3NaOH(aq) \rightarrow Na_3PO_4(aq) + 3H_2O(\ell)$

(c) $2HBr(aq) + Ca(OH)_2(aq) \rightarrow CaBr_2(aq) + 2H_2O(\ell)$

(d) $NH_3(aq) + HClO_4(aq) \rightarrow NH_4ClO_4(aq)$

2. (a) At equivalence, none of the ions present in solution hydrolyze and the solution is neutral.

(b) At equivalence, the solution is basic because the phosphate ion hydrolyzes:

$PO_4^{3-}(aq) + H_2O(\ell) \rightleftharpoons HPO_4^{2-}(aq) + OH^-(aq)$

(c) At equivalence, none of the ions present in solution hydrolyze and the solution is neutral.

(d) At equivalence, the solution is acidic because the ammonium ion hydrolyzes.

$NH_4^+(aq) + H_2O(\ell) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$

3. Congo red is not a suitable indicator for this titration because the pH at equivalence will be 7.0. The endpoint will occur after the equivalence point.
4. Titrating a strong base with a weak acid will result in a solution at equivalence that is basic. Phenolphthalein changes colour over the pH range 8–10, and thus most likely to be a suitable indicator.
5. A diprotic acid was placed in a flask and titrated against NaOH(aq). The first equivalence point occurred after the addition of about 50 mL when the pH was approximately 4.0. The second equivalence point occurred after the addition of about 100 mL when the pH was approximately 9.0.
6. A buffer solution contains two components, one acidic and the other basic. A buffer solution may be made using a weak acid and a salt that contains its conjugate base, or by using a weak base and a salt that contains its conjugate acid.
7. An aqueous mixture of NaCl(aq) and HCl(aq) does not act as a buffer because HCl(aq) is a strong acid and its conjugate base is so weak that it does not hydrolyze. An aqueous mixture of $NH_3(aq)$ and $NH_4Cl(aq)$ does act as a buffer because $NH_3(aq)$ is a weak base, and the ammonium ion hydrolyzes to act as an acid.
8. Blood buffers maintain the pH of blood within a very narrow range, pH 7.4 ± 0.4. Outside this range, very serious health consequences can result.

Student Textbook pages 720–721

Answers to Understanding Concepts Questions

1. In the unpolluted rainwater, $[H_3O^+(aq)] = 2.51 \times 10^{-6}$. In the acid rain sample, $[H_3O^+(aq)] = 3.02 \times 10^{-5}$.

Thus, the acid rain sample has more hydronium ion by a factor of

$$\frac{3.02 \times 10^{-5}}{2.51 \times 10^{-6}} = 12$$

2. Major contributions to NO_x are from automobiles and trucks. Developing countries have far fewer vehicles per person compared with developed countries such as Canada. As developing countries obtain more vehicles, the proportion of NO_x emitted will increase.

3. **(a)** The shampoo is basic.

   (b) $$K_w = [H_3O^+(aq)] \times [OH^-(aq)]$$

   $$[H_3O^+(aq)] = \frac{K_w}{[OH^-(aq)]} = \frac{1.0 \times 10^{-14}}{6.8 \times 10^{-5}}$$

   $$[H_3O^+(aq)] = 1.5 \times 10^{-10} \text{ mol/L}$$

   (c) $pH = -\log(1.5 \times 10^{-10}) = 9.83$;
   $pOH = -\log(6.8 \times 10^{-5}) = 4.17$

4. $pOH = 14.0 - pH = 14.0 - 5.53 = 8.47$

   $[H_3O^+(aq)] = 10^{-pH} = 10^{-5.53} = 3.0 \times 10^{-6}$ mol/L

   $[OH^-(aq)] = 10^{-pOH} = 10^{-8.47} = 3.4 \times 10^{-9}$ mol/L

5. Phenol is acidic.

   $[H_3O^+(aq)] = 10^{-pH} = 10^{-4.72} = 1.9 \times 10^{-5}$ mol/L

   $pOH = 14.0 - pH = 14.0 - 4.72 = 9.28$

   $[OH^-(aq)] = 10^{-pOH} = 10^{-9.28} = 5.2 \times 10^{-10}$ mol/L

6. The patient's blood has $pOH = -\log(2.34 \times 10^{-7}) = 6.625$. Therefore, the blood pH is determined to be $pH = 14.0 - 6.625 = 7.375$. This is at the very high end of the allowable range for blood pH, indicating the patient has alkalosis.

7. The conjugate base of PABA is $C_6H_4NH_2COO^-$.

8. **(a)** The conjugate acid-base pairs are $H_3BO_3(aq)$/$H_2BO_3^-(aq)$ and $H_3O^+(aq)/H_2O(\ell)$

   (b) Boric acid is not one of the strong acids, therefore it is weak.

9. **(a)** Butyric acid is a weak acid.

   (b) Hydroiodic acid is a strong acid.

   (c) Potassium hydroxide is a strong base.

   (d) Iron(III) oxide is a weak base.

10. **(a)** $SO_4^{2-}(aq)$

    (b) $S^{2-}(aq)$

    (c) $HPO_4^{2-}(aq)$

    (d) $CO_3^{2-}(aq)$

11. When a small amount of acid is added to this buffer, the added hydronium ion will be removed as it combines with the methanoate ion, $HCOO^-(aq)$. The addition of a small amount of base would be neutralized by reaction with the methanoic acid.

Answers to Applying Concepts Questions

12. The ICE table for this problem is:

$$CH_3CHOHCOOH(aq) + H_2O(\ell) \rightleftharpoons CH_3CHOHCOO^-(aq) + H_3O^+(aq)$$

	$[CH_3CHOHCOOH(aq)]$ (mol/L)	$[H_2O(\ell)]$ (mol/L)	$[CH_3CHOHCOO^-(aq)]$ (mol/L)	$[H_3O^+(aq)]$ (mol/L)
Initial	0.12		0	~0
Change	−x		+x	+x
Equilibrium	0.12 − x		x	x

$$\frac{[CH_3CHOHCOOH(aq)]}{K_a} = \frac{0.12}{1.38 \times 10^{-4}} = 870$$

This is close to 1000, and the approximation may be valid. At equilibrium,

$[CH_3CHOHCOOH(aq)] \approx 0.12$ mol/L

$$K_a = \frac{[CH_3CHOHCOO^-(aq)][H_3O^+(aq)]}{[CH_3CHOHCOOH(aq)]}$$

$$= 1.38 \times 10^{-4}$$

$$\frac{x^2}{0.12} = 1.38 \times 10^{-4}$$

$$x = 4.07 \times 10^{-3}$$

$0.12 - 4.07 \times 10^{-3} = 0.116$; the approximation is valid.

$[H_3O^+(aq)] = 4.07 \times 10^{-3}$ mol/L

pH = 2.39

13. The molar mass of salicylic acid, $C_6H_4(OH)COOH$, is 138.1 g/mol.

$$\text{Amount } C_6H_4(OH)COOH = \frac{0.22 \text{ g}}{138.1 \text{ g/mol}}$$

$$= 1.59 \times 10^{-3} \text{ mol}$$

$$[CH_3CHOHCOOH(aq)] = \frac{1.59 \times 10^{-3} \text{ mol}}{0.100 \text{ L}}$$

$$= 1.59 \times 10^{-2} \text{ mol/L}$$

$[H_3O^+(aq)] = 10^{-2.43} = 3.72 \times 10^{-3}$ mol/L

$$C_6H_4(OH)COOH(aq) + H_2O(\ell) \rightleftharpoons C_6H_4(OH)COO^-(aq) + H_3O^+(aq)$$

	$[C_6H_4(OH)COOH(aq)]$ (mol/L)	$[H_2O(\ell)]$ (mol/L)	$[C_6H_4(OH)COO^-(aq)]$ (mol/L)	$[H_3O^+(aq)]$ (mol/L)
Initial	1.59×10^{-2}		0	~0
Change	-3.72×10^{-3}		$+3.72 \times 10^{-3}$	$+3.72 \times 10^{-3}$
Equilibrium	1.22×10^{-2}		3.72×10^{-3}	3.72×10^{-3}

$$K_a = \frac{[C_6H_4(OH)COO^-(aq)][H_3O^+(aq)]}{[C_6H_4(OH)COOH(aq)]}$$

$$K_a = \frac{(3.72 \times 10^{-3})^2}{1.22 \times 10^{-2}} = 1.13 \times 10^{-3}$$

$$K_a = 1.1 \times 10^{-3}$$

14.

Acid	K_a	Conjugate Base	$K_b = \frac{K_w}{K_a}$
HCOOH(aq)	1.8×10^{-5}	$HCOO^-(aq)$	5.6×10^{-10}
HF(aq)	6.3×10^{-4}	$F^-(aq)$	1.6×10^{-11}
$C_6H_5COOH(aq)$	6.3×10^{-5}	$C_6H_5COO^-(aq)$	1.6×10^{-10}
HCN(aq)	6.2×10^{-10}	$CN^-(aq)$	1.6×10^{-5}

The order of increasing base strength is
$F^-(aq) < C_6H_5COO^-(aq) < HCOO^-(aq) < CN^-(aq)$

15. $K_w = [H_3O^+(aq)][OH^-(aq)]$

In pure water, $[H_3O^+(aq)] = [OH^-(aq)]$

$$[H_3O^+(aq)] = [OH^-(aq)] = \sqrt{K_w} = \sqrt{2.5 \times 10^{-14}}$$
$$= 1.6 \times 10^{-7}$$

$[H_3O^+(aq)] = [OH^-(aq)] = 1.6 \times 10^{-7}$ mol/L

pH = pOH = 6.80

Pure water at this (or any other) temperature is neutral.

16. The conjugate base is $OBr^-(aq)$.

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{2.1 \times 10^{-9}} = 4.8 \times 10^{-6}$$

17. The weaker base is ammonia. Therefore, the stronger acid will be $NH_4^+(aq)$.

18. $NH_4NO_3(aq) \rightarrow NH_4^+(aq) + NO_3^-(aq)$

Only the ammonium ion hydrolyzes.

K_a for $NH_4^+(aq) = 5.6 \times 10^{-10}$

$$\frac{[NH_4^+(aq)]}{K_a} = \frac{0.1}{5.6 \times 10^{-10}} >> 1000$$

$$NH_4^+(aq) + H_2O(\ell) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$$

	$[NH_4^+(aq)]$ (mol/L)	$[H_2O(\ell)]$ (mol/L)	$[NH_3(aq)]$ (mol/L)	$[H_3O^+(aq)]$ (mol/L)
Initial	0.10		0	~0
Change	$-x$		$+x$	$+x$
Equilibrium	$0.10 - x$ ≈ 0.10		x	x

$$K_a = \frac{[NH_3(aq)][H_3O^+(aq)]}{[NH_4^+(aq)]} = 5.6 \times 10^{-10}$$

$$5.6 \times 10^{-10} = \frac{x^2}{0.10}$$

$$x = [H_3O^+(aq)] = 7.48 \times 10^{-6}$$

$$pH = 5.1$$

19. $NaOCl(aq) \rightarrow Na^+(aq) + OCl^-(aq)$

K_a for $HOCl(aq) = 4.0 \times 10^{-8}$.

$$K_b \text{ for } OCl^-(aq) = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{4.0 \times 10^{-8}} = 2.5 \times 10^{-7}$$

$$M_{NaOCl} = 74.4 \text{ g/mol}$$

$$n_{NaOCl} = \frac{5.0 \text{ g}}{74.4 \text{ g/mol}} = 6.72 \times 10^{-2} \text{ mol}$$

$$[OCl^-(aq)] = \frac{6.72 \times 10^{-2} \text{ mol}}{0.100 \text{ L}} = 6.72 \times 10^{-1} \text{ mol/L}$$

$$\frac{[OCl^-(aq)]}{K_b} = \frac{6.72 \times 10^{-1}}{2.5 \times 10^{-7}} >> 1000$$

$$OCl^-(aq) + H_2O(\ell) \rightleftharpoons HOCl(aq) + OH^-(aq)$$

	$[OCl^-(aq)]$ (mol/L)	$[H_2O(\ell)]$ (mol/L)	$[HOCl(aq)]$ (mol/L)	$[OH^-(aq)]$ (mol/L)
Initial	6.72×10^{-1}		0	~0
Change	$-x$		$+x$	$+x$
Equilibrium	$6.72 \times 10^{-1} - x$ $\approx 6.72 \times 10^{-1}$		x	x

$$K_b = \frac{[HOCl(aq)][OH^-(aq)]}{[OCl^-(aq)]} = 2.5 \times 10^{-7}$$

$$2.5 \times 10^{-7} = \frac{x^2}{6.72 \times 10^{-1}}$$

$x = [OH^-(aq)] = 4.10 \times 10^{-4}$ mol/L

pOH = 3.39

pH = 10.61.

20. (a) $K_a = \frac{[PO_4^{3-}(aq)][H_3O^+(aq)]}{[HPO_4^{2-}(aq)]}$

(b) $K_b = \frac{[H_2PO_4^-(aq)][OH^-(aq)]}{[HPO_4^{2-}(aq)]}$

(c) An aqueous solution of sodium hydrogen phosphate will be basic because $K_b > K_a$.

Answers to Solving Problems Questions

21. There are four major types of coal: lignite, sub-bituminous, bituminous and anthracite. The coal on Alberta's plains is mainly sub-bituminous, which does not require processing for use as a fuel in electricity generating plants. Bituminous coal is mined in the Foothills and mountainous regions, and this must be upgraded or processed before it can be used. Sulfur dioxide emissions from coal fuels may be reduced during combustion or from the flue gases after combustion. Lime or limestone can be added to the coal to absorb $SO_2(g)$ as it is released during combustion. Sulfur dioxide can be removed from flue gases by passing the gas through a spray tower where calcium carbonate reacts with $SO_2(g)$ to form calcium sulfite and calcium sulfate. The reaction products are treated to form gypsum, which has a number of uses including the manufacture of wallboard for the building industry. In the ammonia scrubbing process, aqueous ammonia is used in a spray tower, and the $SO_2(g)$ reacts to form ammonium sulfate which can be recovered and sold as fertilizer.

22. Sodium hypochlorite reacts with water to produce the hypochlorous acid needed to kill germs and algae:

$$NaOCl(aq) + H_2O(\ell) \rightarrow HOCl(aq) + Na^+(aq) + OH^-(aq)$$

The relative amounts of HOCl and OCl^- change with pH, and the ideal range is 7.2 – 7.8. This is why the pH of a pool must be tested regularly. If the pH is too low, the water is too acidic and the acid may make swimmers' eyes sore. Also, the acid would attack concrete pools or the mortar between tiles, as these materials contain calcium carbonate.

23. $H_2S(aq)$: $K_a = 8.9 \times 10^{-8}$

$H_2SO_3(aq)$: $K_a = 1.4 \times 10^{-2}$

(a) HS^-: $K_b = \dfrac{[H_2S(aq)][OH^-(aq)]}{[HS^-(aq)]}$

HSO_3^-: $K_b = \dfrac{[H_2SO_3(aq)][OH^-(aq)]}{[HSO_3^-(aq)]}$

(b) $K_b = \dfrac{K_w}{K_a}$

$HS^-(aq)$: $K_b = \dfrac{1.1 \times 10^{-14}}{8.9 \times 10^{-8}} = 1.2 \times 10^{-7}$

$HSO_3^-(aq)$: $K_b = \dfrac{1.0 \times 10^{-14}}{1.4 \times 10^{-2}} = 7.1 \times 10^{-13}$

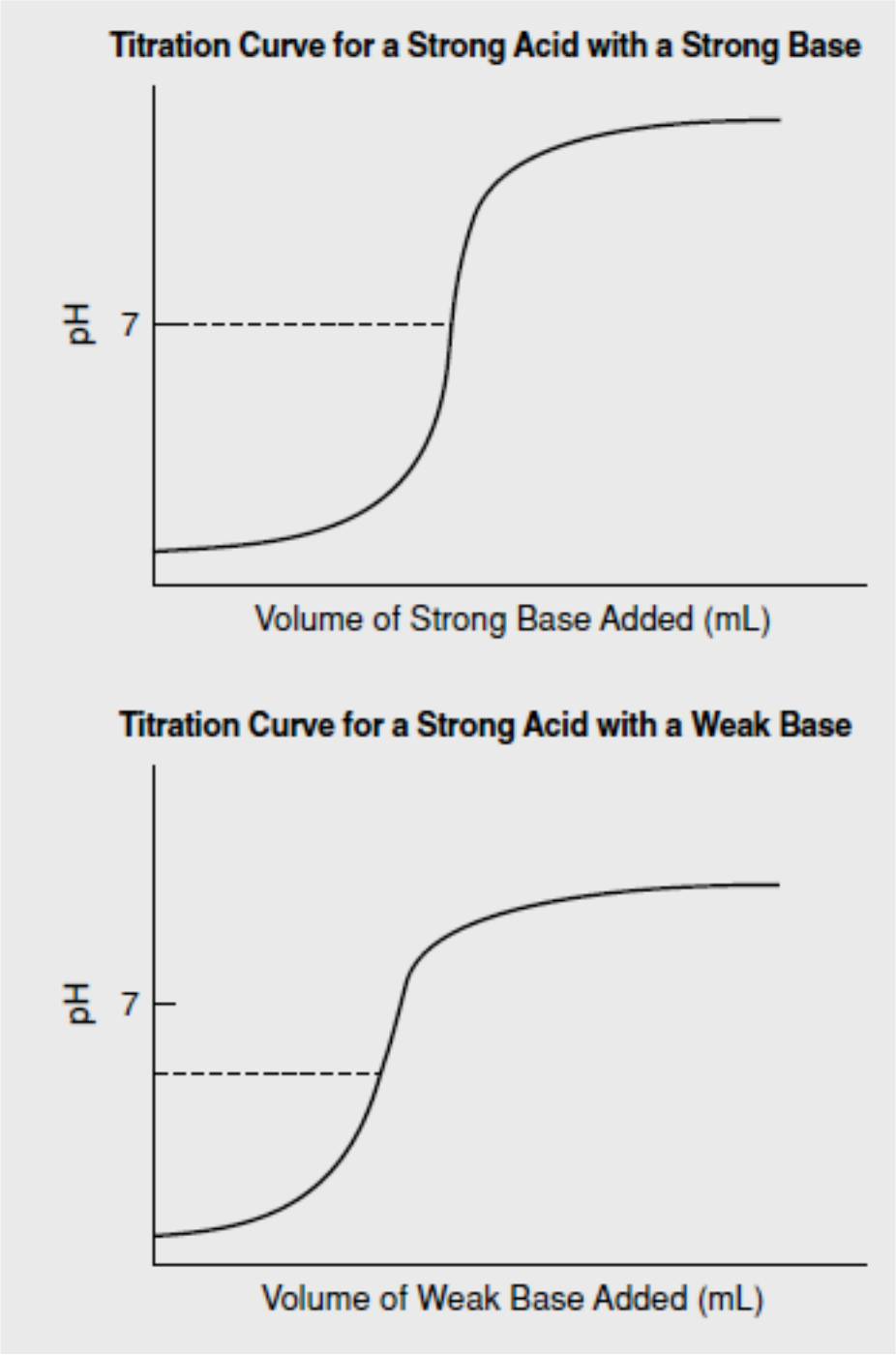
(c) $HS^-(aq)$ is the stronger base because it has a larger value for K_b.

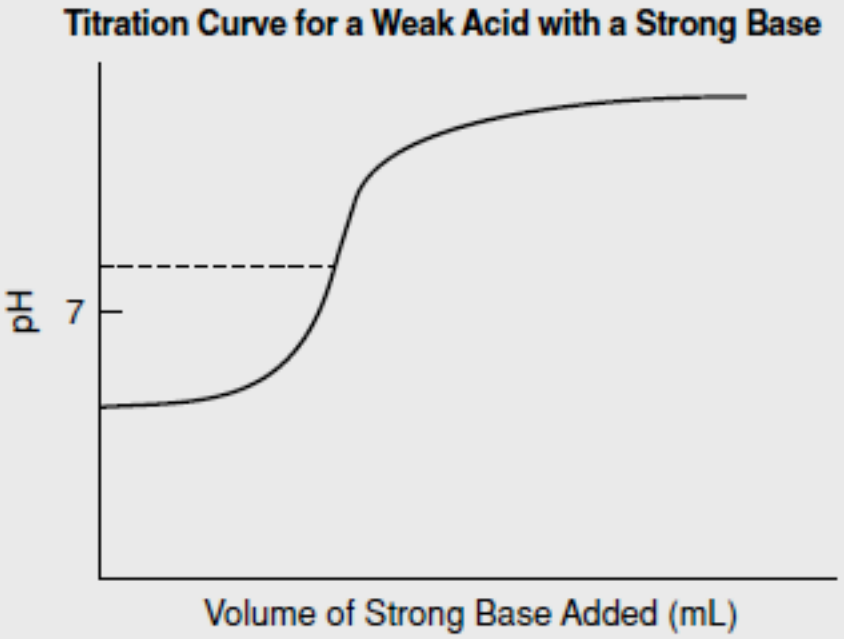
24. Each equilibrium lies to the right, therefore, the stronger acid is on the left of the equation. Thus, each equation gives the following relative strengths:

$HBrO_2(aq) > CH_3COOH(aq)$; $H_2S(aq) > H_2O(\ell)$; and $CH_3COOH(aq) > H_2S(aq)$.

Therefore, the order is $HBrO_2(aq) > CH_3COOH(aq) > H_2S(aq) > H_2O(\ell)$.

25. (a)


Titration Curve for a Strong Acid with a Strong Base
pH
7
Volume of Strong Base Added (mL)
Titration Curve for a Strong Acid with a Weak Base
pH
7
Volume of Weak Base Added (mL)



(b) Congo red would be a good indicator for the titration of a strong acid with a weak base.

26. Boric acid is very weak ($K_a = 5.9 \times 10^{-10}$). Therefore the borate ion is a relatively strong base. Because K_b for the borate ion is greater than K_a for boric acid, the buffer is basic.

Answers to Making Connections Questions

27. (a) In the student textbook, the environmental issue of acid rain is extended beyond students' previous knowledge by including chemical equilibrium and Le Châtelier's principle. Students are likely to mention facts that relate to either or both of these concepts.

(b) Some possible questions include:

Does the pH of acid deposition change with the seasons?

Design an experiment to investigate the effect of acid rain on leaves.

How do controls fitted to vehicles reduce $SO_x(g)$ and $NO_x(g)$?

Draw a map of North America showing the location of coal burning power plants, prevailing winds, and regions with low pH acid deposition.

The rubric used to assess the research project must be specific to the actual project, and should contain qualitative descriptions of performance criteria.

28. For the most dilute solution,

$$\frac{[C_6H_5COOH(aq)]}{K_a} = \frac{0.01}{6.3 \times 10^{-5}} = 159$$

Thus, the approximation may not be valid for this solution. However, the approximation will be valid for the other concentrations. Since the question is looking for a trend, assume the approximation is valid for each dilute solution.

(a) $C_6H_5COOH(aq) + H_2O(\ell) \rightleftharpoons C_6H_5COO^-(aq) + H_3O^+(aq)$

	$[C_6H_5COOH(aq)]$ (mol/L)	$[H_2O(\ell)]$ (mol/L)	$[C_6H_5COO^-(aq)]$ (mol/L)	$[H_3O^+(aq)]$ (mol/L)
Initial	1.0		0	~0
Change	−x		+x	+x
Equilibrium	1.0 − x ≈ 1.0		x	x

$$K_a = \frac{[C_6H_5COO^-(aq)][H_3O^+(aq)]}{[C_6H_5COOH(aq)]}$$

$$6.3 \times 10^{-5} = \frac{x^2}{1.0}$$

$$x = [H_3O^+(aq)] = 7.94 \times 10^{-3} \text{ mol/L}$$

$$\text{pH} = 2.10$$

$$\text{percent ionization} = \frac{7.94 \times 10^{-3}}{1.0} \times 100 = 0.79\%$$

(b) By similar calculations, the 0.10 mol/L solution benzoic acid has pH = 2.60 and is 2.5% ionized.

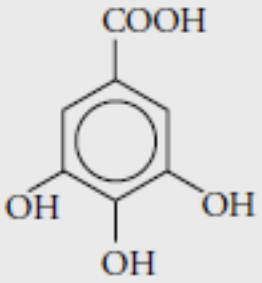
(c) The 0.01 mol/L solution has pH = 3.10 and is 7.9% ionized.

As the solution becomes more dilute, more benzoic acid molecules ionize.

$$C_6H_5COOH(aq) + H_2O(\ell) \rightleftharpoons C_6H_5COO^-(aq) + H_3O^+(aq)$$

Le Châtelier's principle predicts that as more water is added, the equilibrium will shift to the right causing greater ionization and increased $[H_3O^+(aq)]$. This matches the results of the calculations.

29. (a)



(b) The conjugate base is $C_6H_5(OH)_3COO^-$.

$$K_b = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{3.9 \times 10^{-5}} = 2.6 \times 10^{-10}$$